UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY, COAL RESOURCES, AND COAL QUALITY OF THE PRAIRIE DOG CREEK EMRIA STUDY AREA, ROSEBUD COUNTY, MONTANA

By

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Abstract

The 9800-acre (40-sq-km) Prairie Dog Creek EMRIA study area is located on the northwest flank of the northern Powder River Basin. Three major coal beds, in ascending order, the Wall, Cook, and Canyon, occur in gently southeast-dipping strata of the Tongue River Member of the Paleocene Fort Union Formation.

The Wall bed, reaching 62.5 feet (19.1 m) in thickness, contains 360 million short tons (327 million metric tons) of potentially surface-minable coal under less than 200 feet (61 m) of overburden. The Canyon and Cook beds contain resources of 35 million short tons (32 million metric tons) and 26 million short tons (24 million metric tons), respectively, under less than 200 feet (61 m) of overburden.

Additional resources from the three coal beds may be 300 million short tons (272 million metric tons) if 500 feet (152 m) of overburden is removed from the Wall bed.

Analyses of samples from core holes indicate that the apparent rank of the Wall coal bed is subbituminous B; the Canyon and Cook coal beds, subbituminous C. The three coal beds are well below the national average in ash and sulfur content.

Introduction

As a contribution to the study of the reclamation potential for surface mining, this report describes the geology and coal resources in a 9800-acre (40-sq-km) area located in the northern part of the Powder River Basin, T. 6 S., R. 41 E., Rosebud County, Mont. The Prairie Dog Creek study area was selected by the U.S. Bureau of Land Management for investigation as part of the Energy Minerals Rehabilitation Inventory and Analysis (EMRIA) Program. The area, including parts of the Birney SW and Taintor Desert 7.5-minute quadrangles, was mapped geologically in 1978 and 1979 by S. A. Volz (pl. 1).

Particular attention was focused on three coal beds in the Tongue River Member of the Fort Union Formation of Paleocene age: the Wall, Canyon, and Cook. Data on the coal beds were obtained from 18 drill holes in and near the study area, 10 of which were cored in 1978 and 1979 by the U.S. Bureau of Reclamation (table 1). Thirty-nine core samples of coal from six beds were analyzed to determine the composition and quality of the coal; the results of these analyses were statistically analyzed and are reported here by R. H. Affolter.

Table 1.--Drill holes in and near the Prairie Dog Creek study area used in coal resource evaluation

[USBR = U.S. Bureau of Reclamation; USGS = U.S. Geological Survey; MBMG = Montana Bureau of Mines and Geology. 1 ft = 0.305 m]

Map No.	Hole name and location	Surface elevation (in feet)	Cored interval (in feet)	Geophysical[1/] logs
A	USBR DH 79-110 NE 1/4 sec. 5, T. 6 S., R. 41 E.	3795	0.5-174.0	
B	USBR DH 79-108 NE 1/4 sec. 6, T. 6 S., R. 41 E.	4025	.5-373.0	
C	MBMG SH 121 NE 1/4 sec. 12, T. 6 S., R. 40 E.	3865	---	2/
D	USBR DH 78-102 NW 1/4 sec. 7, T. 6 S., R. 41 E.	3910	.5-302.0	
E	USBR DH 78-105 SW 1/4 sec. 8, T. 6 S., R. 41 E.	3740	2.5-386.5	
F	USGS and MBMG US 76137 SW 1/4 sec. 8, T. 6 S., R. 41 E.	3720	---	Gamma Ray Density
G	USBR DH 79-106 SE 1/4 sec. 8, T. 6 S., R. 41 E.	3770	.5-220.0	
H	USGS water well, PDC 5 NW 1/4 sec. 16, T. 6 S., R. 41 E.	3705	---	Gamma Ray
I	USBR DH 79-107 SE 1/4 sec. 15, T. 6 S., R. 41 E.	3860	1.5-333.0	
J	MBMG SH 46 SW 1/4 sec. 16, T. 6 S., R. 41 E.	3601	40.0-89.0	2/
K	USBR DH 79-112 SE 1/4 sec. 18, T. 6 S., R. 41 E.	3805	1.0-214.5	
L	USBR DH 78-103 NW 1/4 sec. 21, T. 6 S., R. 41 E.	3620	.5-274.0	
M	MBMG SH 45 SW 1/4 sec. 21, T. 6 S., R. 41 E.	3586	57-104.0	2/
N	USBR DH 78-101 NE 1/4 sec. 29, T. 6 S., R. 41 E.	3830	2.0-399.0	
O	USGS water well, PDC 9 NE 1/4 sec. 29, T. 6 S., R. 41 E.	3835	---	Gamma Ray
P	USGS water well, PDC 11 NW 1/4 sec. 33, T. 6 S., R. 41 E.	3710	---	Gamma Ray
Q	USBR DH 79-111 SW 1/4 sec. 33, T. 6 S., R. 41 E.	3690	1.5-383.0	
R	USGS water well, PDC 13 SW 1/4 sec. 34, T. 6 S., R. 41 E.	3465	---	Gamma Ray

1/ Logs used for interpreting thickness of coal beds

2/ Data on these holes from Matson and others (1973) includes analyses of the Wall bed in SH-45 and SH-46.

Previous Investigations

The general geology of the Prairie Dog Creek study area was first mapped in the 1920's by Baker (1929) as part of a study of the northward extension of the Sheridan coal field. Later, Matson and others (1973) examined the area for strippable coal deposits. In 1978 and 1979, S. A. Volz (written communication, 1979) mapped the geology and coal deposits in the Birney SW and Taintor Desert 7.5-minute quadrangles and furnished the geologic map on plate 1.

Structural Setting

The Prairie Dog Creek study area lies on the gently dipping northwest flank of the northern Powder River Basin. In the study area the strata dip less than 1 degree to the southeast, and only locally are the strata affected by monoclinal folds and east-northeast-trending normal faults (pl. 2). Along the faults the strata are displaced a maximum of 100 feet (30 m), down to the south.

Stratigraphy

A generalized stratigraphic section of the Upper Cretaceous through Eocene rocks of the northern Powder River Basin is presented in table 2. The Prairie Dog Creek study area lies completely within the outcrop belt of the Tongue River Member of the Fort Union Formation (pl. 1). The principal coal-bearing part of the Tongue River Member in this area is about 700 feet (213 m) thick and locally contains 11 coal beds, of which 7 are more than 5 feet (1.5 m) thick. The non-coal rocks of this sequence consist of interbedded fine-grained to very fine grained sandstone, clayey siltstone, silty shale, and carbonaceous shale (see fig. 1).

The thicker coal beds have burned back from the outcrop in much of the study area. The resulting heat has baked and fused the overlying rocks into a brittle, resistant, red rock called clinker. Clinker beds are a prominent feature of the Prairie Dog Creek area.

Table 2.--Generalized stratigraphic section of the northern Powder River Basin

Age	Formation		Lithology
Eocene	Wasatch		Shale, sandstone, coal
Paleocene	Fort Union	Tongue River Member	Sandstone shale, siltstone, coal
		Lebo Shale Member	Dark shale
		Tullock Member	Shale, sandstone, minor coal
Late Cretaceous	Hell Creek		Sandstone, shale

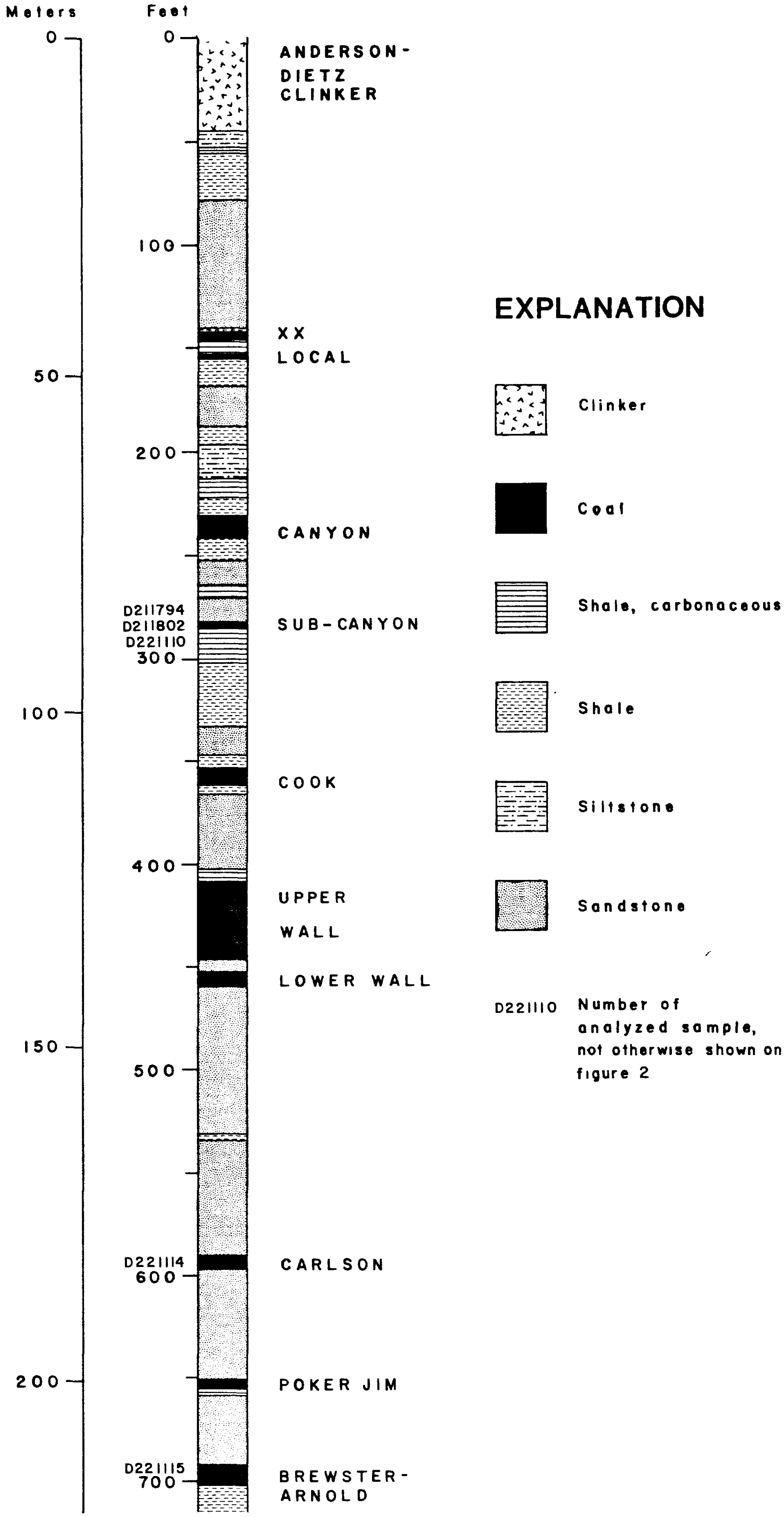

Figure 1 – Composite columnar section showing relations of Wall and Canyon beds to other coal beds in the Fort Union Formation. Section above Canyon from S. A. Volz (written communication, 1979)

Sediments in the Tongue River Member accumulated some 50 million years ago in rivers, flood plains, small lakes, and abundant swamps which migrated back and forth over a broad, flat alluvial plain.

The stream bottoms of Prairie Dog Creek and its tributaries are underlain by Quaternary alluvium which consists of unconsolidated sand, silt, clay, and gravel.

Coal Geology

The most important coal bed in this investigation is the Wall bed, which is 31.5 to 62.5 feet (9.6 to 19.1 m) thick in the study area. This coal bed generally thickens to the southwest, as shown by the isopach map on plate 2. The Wall bed is significantly thinner at locality Q than in nearby test holes, probably because of its location near a fault (pl. 2 and fig. 2).

Data from drill holes indicate that a parting exists in many places (fig. 2). In the southern part of the area the parting is 2 feet (0.6 m) or less in thickness, but it thickens to 7.8 feet (2.4 m) in the west-central part of area. Apparently it also thickens eastward because the Wall is represented on the eastern outcrop by two clinker beds as much as 60 feet (18.3 m) apart. Where the parting is more than 3 feet (1 m) thick, the upper and lower benches are here referred to as Upper and Lower Wall. The Lower Wall is 5.5 to 7.1 feet (1.7 to 2.2 m) thick, and the Upper Wall is 32.5 to 44.0 feet (9.9 to 13.4 m) thick.

The Wall coal bed is not exposed in the area. It burned back from its outcrop almost everywhere and formed clinker as much as 180 feet (55 m) thick in the southern part of the area.

The Cook bed is 2.6 to 8.6 feet (0.8 to 2.6 m) thick (fig. 2); it is 47 to 133 feet (14 to 41 m) above the Wall in six drill holes (pl. 4), but is missing entirely in holes at K, N, and O. Outcrop measurements range from 2.1 to 3.4 feet (0.6 to 1 m) (pl. 4). The geologic map indicates that the Cook is concealed or missing along most of its projected outcrop (pl. 1), but, for the purpose of calculating resources, an outcrop, or a limit of burned coal, was inferred from drill-hole and other data in the area (pl. 4).

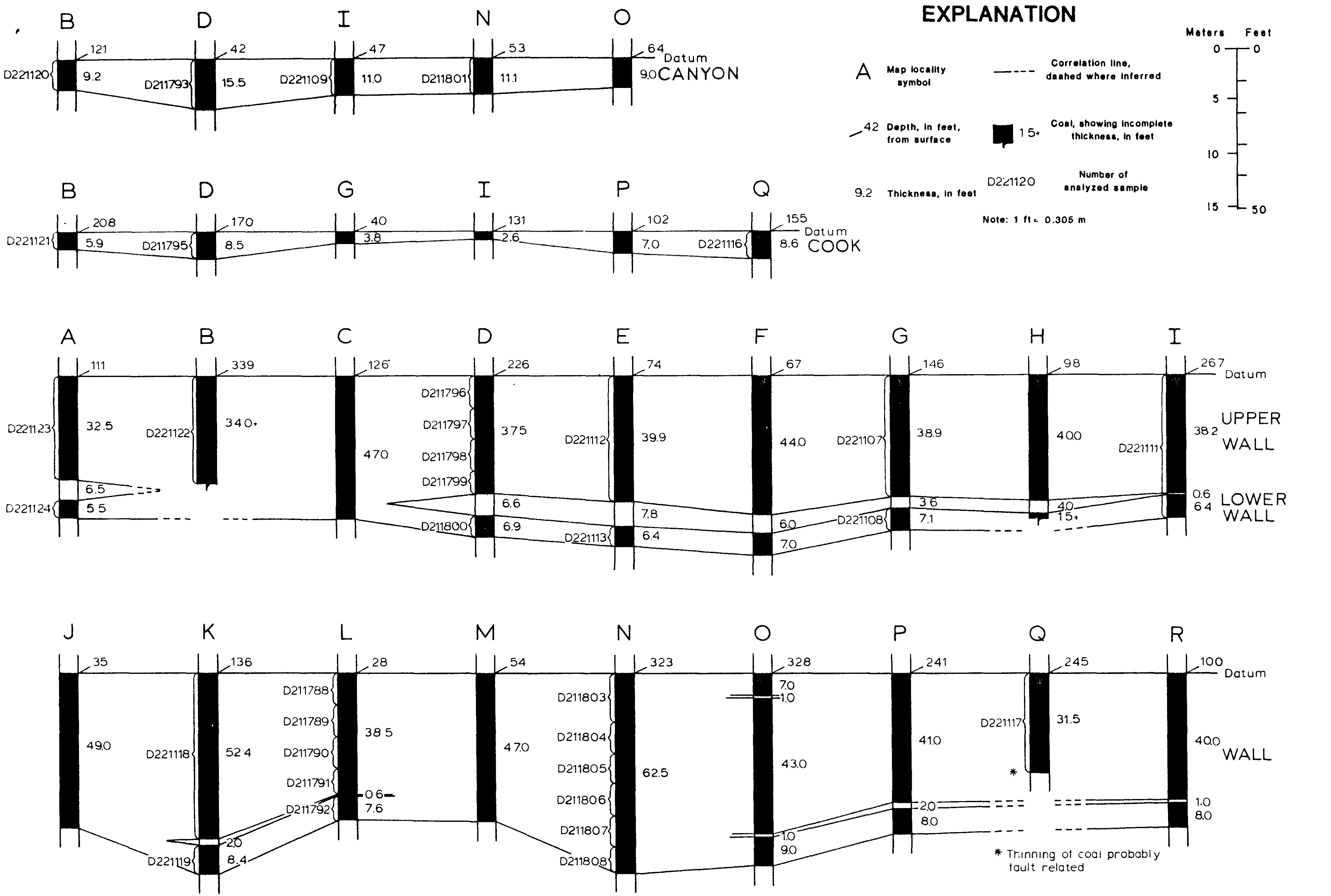

Figure 2 – Coal sections from drill holes in the Prairie Dog Creek study area

The sub-Canyon coal bed occurs between 120 and 220 feet (37-67 m) above the Wall in six drill holes. It is 1.0 foot thick (0.3 m) at hole B, 2.6 feet (0.8 m) at D, 6.0 feet (1.8 m) at I, 4.5 feet (1.4 m) at N, 4.0 feet (1.2 m) at O, and 3.5 feet (1.1 m) at P. The sub-Canyon was recognized on the outcrop only in the southern part of the study area (pl. 1).

The second most important coal bed in this area is the Canyon bed which is 160 to 260 feet (49-79 m) above the Wall (pl. 3). It is 9 to 15.5 feet (3 to 5 m) thick in five drill holes (fig. 2), thickening northwestward, but is as thin as 4.5 feet (1.4 m) on the outcrop. It is overlain by not more than 400 feet (120 m) of rock.

Three thin local coal beds lie within 40 to 160 feet (12 to 49 m) above the Canyon and are designated on the map (pl. 1) as L, XX, and X2. Sparse outcrop data indicate that they are 2 to 6 feet (0.6 to 18 m) thick. Remnants of the Anderson-Dietz bed underlie the high ridges in the area and are about 200 feet (61 m) above the Canyon. Much of it has burned, and no thickness data is available where it is not burned.

Beginning about 100 feet (30 m) below the Wall bed is a sequence of three or four coal beds (fig. 1). The uppermost bed, the Carlson, is 7.5 feet (2.3 m) thick and 130 feet (39.6 m) below the Wall in corehole E, but in corehole L it consists of four benches of coal totaling 5.2 (1.6 m) feet in an 8.1-foot (2.5-m) bed at 106 feet (32.3 m) below the Wall. The next bed, the Poker Jim, consists of interbedded coal and shale in both core holes. In corehole E it contains 4.5 feet (1.4 m) of coal in a 6.7-foot (2.0-m) bed that is 54 feet (16.5 m) below the Carlson and in corehole L it contains 4.5 feet (1.4 m) of coal in a 10.0-foot (3 m) bed. The thickest bed in this sequence is the Brewster-Arnold, which is 10.2 feet (3.1 m) thick at 237 feet (72.2 m) below the Wall in corehole E, the only core hole that penetrated it. However, data from two oil and gas test holes (Culbertson, 1980) indicate that another bed, the Odell, lies 2 to 15 feet (0.6 to 4.6 m) below the Brewster-Arnold and is 6 to 7 feet (1.8 to .1 m) thick.

Coal

Origin

Coal has been defined as "a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade), are characteristics of the varieties of coal" (Schopf, 1956). Coal deposits originated as a mixture of plant remains and inorganic mineral matter that accumulated in a manner similar to that in which modern-day peat deposits are formed. The peat then underwent a long, extremely complex process called "coalification," during which diverse physical and chemical changes occurred as the peat changed to coal, and the coal assumed the characteristics that differentiate it from other members of the coal series. The factors that affect the composition of coals have been summarized by Francis (1961, p. 2) as follows:

1) The mode of accumulation and burial of the plant debris forming the deposits.
2) The age of the deposits and their geographical distribution.
3) The structure of the coal-forming plant, particularly details of structure that affect chemical composition or resistance to decay.
4) The chemical composition of the coal-forming debris and its resistance to decay.
5) The nature and intensity of the plant-decaying processes.
6) The subsequent geological history of the residual products of decay of the plant debris forming the deposits.

The reader may refer to such standard works as Moore (1940), Lowry (1945, 1963), Tomkeieff, (1954), and Francis (1961) for further discussion of these factors.

Classification

Although coals can be classified in many ways (Tomkeieff, 1954, p. 9; Moore, 1940, p. 113; Francis, 1961, p. 361), classification by rank is the most commonly used system. Rank refers to the degree of metamorphism in the progressive series that begins with peat and ends with graphocite (Schopf, 1966). When sufficient megascopic and microscopic information is available classification by type of plant materials is commonly used as a descriptive adjunct to classification by rank. Classification by type and quantity of impurities (grade) or by coking qualities is often used.

Rank of coal

The designation of a coal within the metamorphic series, which begins with peat and ends with graphocite, is dependent upon the temperature and pressure to which the coal has been subjected and the length of time of subjection. Because coal is largely derived from plant material, it is mostly composed of carbon, hydrogen, and oxygen, along with smaller quantities of nitrogen, sulfur, and other elements. As coal undergoes progressive metamorphism, the increase in rank is indicated by changes in the proportions of the major coal constituents: a higher rank coal has more fixed carbon and less hydrogen and oxygen than the lower ranks.

The two standardized forms of coal analyses, the proximate analysis and the ultimate analysis, are described as follows (U.S. Bureau of Mines, 1965, p. 121-122):

> "The proximate analysis of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cakelike residue that burns at higher temperatures after volatile matter has been driven off. Ultimate analysis involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the materials as a whole, and the estimation of oxygen by difference."

Because most coals are burned to produce heat energy, the heating value of the coal is an important property. The heating value (calorific value) is commonly expressed in British thermal units (Btu) per pound: 1 Btu is the amount of heat required to raise the temperature of 1 pound of water $1^{o}F$ (1 Btu per pound = 0.5666 kilocalories per kilogram). Additional tests are sometimes made, particularly to determine forms of sulfur, ash-fusion temperatures, tar yield, caking, coking, and other properties that affect classification, utilization, or preparation of coal.

In histogram form, figure 3 compares the heating value, and the moisture, volatile-matter, and fixed-carbon contents of coals of different ranks.

Various schemes for classifying coals by rank have been proposed and used, but the one most commonly employed in the United States is the "Standard specifications for classification of coals by rank," adopted by the ASTM (American Society for Testing and Materials, 1977; table 1). It is reproduced here as table 3.

In the ASTM classification system, coals are divided into classes and groups according to either the mineral-matter-free fixed carbon or volatile matter content, or the moist-mineral-matter-free heating value, supplemented by determination of agglomerating (caking) characteristics (table 3). "Coals which in the volatile matter determination produce either an agglomerate button that will support a 500-g weight without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating from the standpoint of classification" (ASTM, 1977, p. 216).

Samples of coal must be obtained in accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960) in order to determine a standard rank, as pointed out by the ASTM (1977, p. 216). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank."

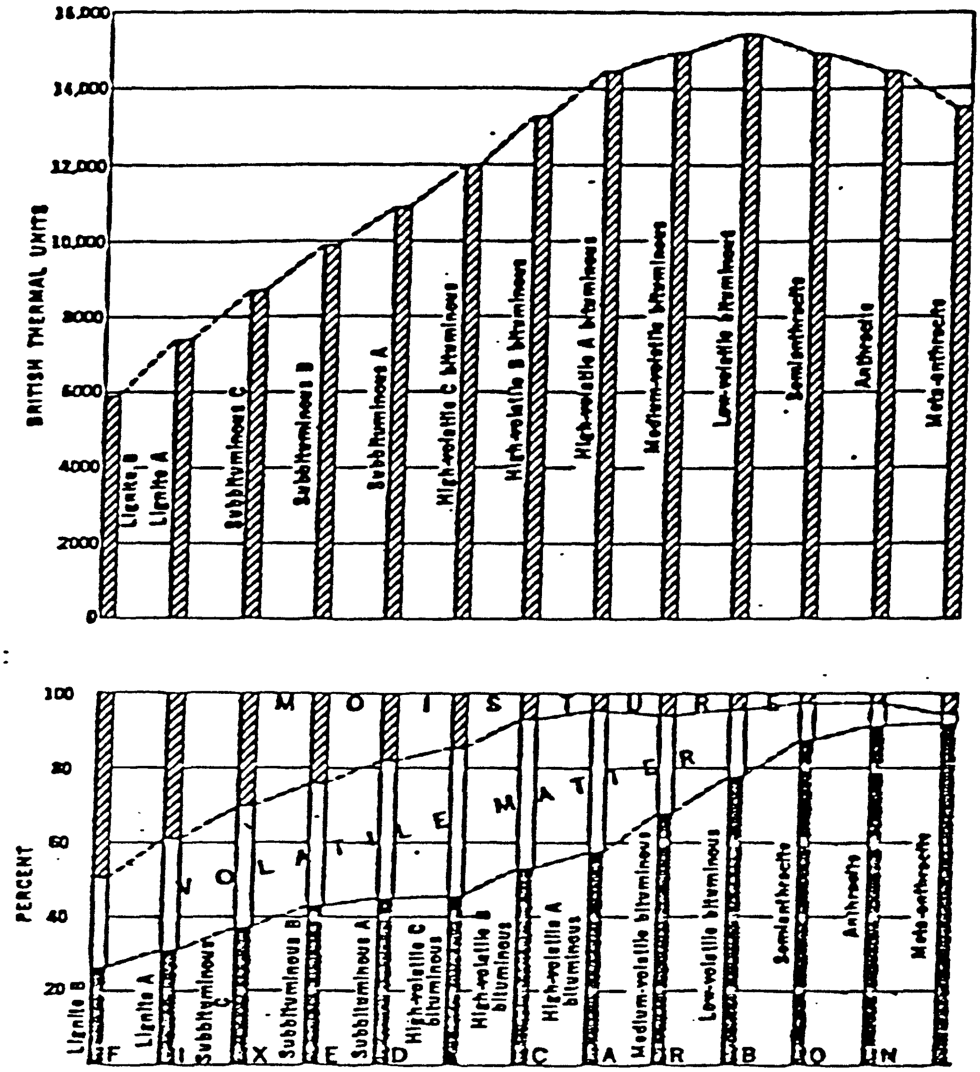

Figure 3.--Comparison on moist, mineral-matter-free basis of heat values and contents of moisture, volatile matter, and fixed carbon of coal of different ranks.

The apparent ranks of the coals at the Prairie Dog Creek study area are subbituminous C and B.

Type of coal

Classification of coals by type of plant materials present takes many forms, such as the "rational analysis" of Francis (1961) or the semicommercial "type" classification commonly used in the coal fields of the eastern United States (U.S. Bureau of Mines, 1965, p. 123). However, the majority of the type classifications are based on the same or similar gross distinctions in plant material to those used by Tomkeieff (1954, table II and p. 9), who divided the coals into three series: humic coals, humic-sapropelic coals, and sapropelic coals, according to the nature of the original plant materials. The humic coals are largely composed of the remains of the woody parts of plants, and the sapropelic coals are largely composed of the more resistant waxy, fatty, and resinous parts of plants, such as cell walls, spore-coatings, pollen, and resin particles. Some sapropelic coals are composed mainly of algal material. Most coals are classified in the humic series, with other coals being mixtures of humic and sapropelic elements and, therefore, classified in the humic-sapropelic series. The sapropelic series is quantitatively insignificant and, when found, is commonly regarded as an organic curiosity.

In common with most coals of the United States, the Prairie Dog Creek coals fall largely in the humic series.

Grade of coal

Classification of coal according to grade is based largely on the content of ash, sulfur, and other constituents that adversely affect utilization. Most detailed coal resource evaluations of the past did not categorize known coal resources by grade, but coals of the United States have been classified by sulfur content in a gross way (DeCarlo and others, 1966).

Compared to other U.S. coals (Swanson and others, 1976; Hatch and Swanson, 1977), coal from the Canyon, Cook, and Wall beds in the Prairie Dog Creek study area is characterized by relatively low ash, low sulfur, low heat of combustion, and high moisture content (table 4). The amounts of elements of environmental concern such as As, Be, Hg, Mo, Sb, and Se are low in the Prairie Dog Creek study area coal when compared to most other U.S. coals.

Chemical analyses of coal in the Prairie Dog Creek study area

Proximate and ultimate analysis,and heat-of-combustion, air-dried-loss, forms-of-sulfur and ash-fusion-temperature determinations on 39 samples from six coal beds (table 4) were provided by chemists from the Coal Analysis Section (John Puskas, Acting Chief), Department of Energy, Pittsburgh, P., whose contribution is gratefully acknowledged.

Analyses for ash content and 31 major and minor oxides and trace elements in the laboratory ash (table 5) and analyses of 9 trace elements in whole coal (table 6) for all 39 samples were provided by the U.S. Geological Survey, Denver. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976).

We gratefully acknowledge the contribution of the team of chemical laboratory personnel in the U.S. Geological Survey under the direction of James L. Seeley: James W. Baker, Ardith J. Bartel, Joseph H. Christie, M. Coughlin, Barbara Keaten, Roy J. Knight, Sally Lasater, Fred E. Lichte, Jane Malcolm, Hugh T. Millard, Harriet G. Neiman, M. Schneider, Gaylord D. Shipley, Wenda Stang, Joseph E. Taggart, James A. Thomas, Robert B. Vaughn, and James S. Wahlberg.

Table 7 contains both the data listed in table 5 converted to a whole coal basis, and the whole-coal analyses that are listed in table 6. Twenty-three additional elements not listed in tables 5, 6, and 7 were looked for but not found in amounts greater than their lower limits of detection (table 8). Unweighted statistical summaries of the analytical data for 39 coal samples from the Prairie Dog Creek study area in tables 4, 5 and 6 are listed in tables 9, 10, and 11. For comparison, data summaries for coal samples from the Powder River region of Montana and Wyoming are included in tables 9, 10, and 11.

Table 4.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, and ash-fusion-temperature determinations for 39 coal samples from Prairie Dog Creek study area, Rosebud County, Montana

[All analyses except heat of combustion and ash-fusion temperatures, in percent. For each sample number, the analyses are reported three ways: first, as received; second, moisture free; and third, moisture and ash free. All analyses by Coal Analysis Section, U.S. Department of Energy, Pittsburgh, Pa. Free-swelling-index not determined. L, less than value show $F^{o} = (C^{o} \times 1.8) + 32$. Leaders (---) indicate no data. All samples are from the Fort Union Formation of Paleocene age. See plate 1 for locations and table 1 for data on drill holes]

				Proximate analysis				Ultimate analysis					Heat of combustion			Forms of sulfur			Ash-fusion temperature, C°		
Sample No.	Map locality	Coal bed	Depth interval in feet (meters)	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb	Air dried loss	Sulfate	Pyritic	Organic	Initial deformation	Softening	Fluid
D221120	B	Canyon	121.3-130.5	28.2	27.5	39.7	4.6	6.2	50.3	1.0	37.4	0.4	4,750	8,550	20.7	0.01L	0.05	0.34	1,020	1,105	1,150
			(37.0-39.8)	---	38.3	55.3	6.4	4.3	70.2	1.4	17.2	.5	6,620	11,910	---	.01L	.07	.47			
				---	41.0	59.0	---	4.6	75.0	1.5	18.4	.6	7,060	12,710	---	.01L	.07	.51			
D211793	D	Canyon	42.5-58.0	30.6	27.3	38.9	3.2	6.7	49.4	1.0	39.4	.4	4,730	8,510	25.4	.01	.04	.33	1,290	1,350	1,395
			(13.0-17.7)	---	39.3	56.1	4.6	4.7	71.2	1.4	17.6	.5	6,820	12,280	---	.01	.05	.48			
				---	41.2	58.8	---	4.9	74.7	1.4	18.4	.6	7,150	12,870	---	.01	.06	.50			
D221109	I	Canyon	47.0-58.0	22.2	25.1	37.3	15.4	5.6	46.4	1.0	31.2	.5	4,360	7,850	16.4	.01	.13	.32	1,160	1,205	1,275
			(14.3-17.7)	---	32.3	48.0	19.7	4.0	59.7	1.2	14.8	.6	5,610	10,090	---	.01	.17	.41			
				---	40.3	59.7	---	5.0	74.4	1.5	18.4	.7	6,980	12,570	---	.01	.21	.51			
D211801	N	Canyon	52.7-63.8	29.5	29.1	38.1	3.3	6.4	50.1	1.1	38.6	.5	4,740	8,530	24.4	.01	.08	.41	1,130	1,180	1,225
			(16.1-19.5	---	41.3	54.0	4.7	4.5	71.1	1.6	17.4	.7	6,730	12,110	---	.01	.11	.58			
				---	43.4	56.6	---	4.7	74.6	1.6	18.3	.7	7,060	12,710	---	.01	.11	.61			
D211794	D	Sub Canyon	99.0-101.6	26.1	26.1	30.6	17.2	5.7	40.0	.8	33.6	2.7	3,880	6,990	20.1	.26	1.50	.92	1,065	1,115	1,160
			(30.2-31.0)	---	35.4	41.3	23.3	3.8	54.2	1.1	14.0	3.6	5,250	9,460	---	.36	2.03	1.24			
				---	46.1	53.9	---	4.9	70.7	1.5	18.3	4.7	6,850	12,330	---	.47	2.65	1.62			
D221110	I	Sub Canyon	79.0-85.0	19.3	27.0	37.0	16.7	5.3	46.0	.9	28.0	3.2	4,420	7,950	13.4	.17	1.91	1.08	1,050	1,110	1,150
			(24.1-25.9)	---	33.4	45.9	20.7	3.9	56.9	1.1	13.4	3.9	5,470	9,840	---	.22	2.36	1.34			
				---	42.1	57.9	---	4.9	71.8	1.4	17.0	4.9	6,900	12,420	---	.27	2.98	1.69			
D211802	N	Sub Canyon	91.0-95.3	27.8	29.1	36.4	6.7	6.4	47.6	.8	36.2	2.2	4,560	8,210	23.9	.14	.94	1.17	1,050	1,100	1,160
			(27.7-29.1)	---	40.3	50.4	9.3	4.6	66.0	1.2	15.9	3.1	6,320	11,380	---	.19	1.30	1.61			
				---	44.4	55.6	---	5.0	72.7	1.3	17.5	3.4	6,970	12,540	---	.21	1.43	1.78			
D221121	B	Cook	208.1-214.0	27.3	28.3	39.0	5.4	6.2	50.4	.9	36.7	.4	4,740	8,530	21.1	.01L	.03	.37	1,040	1,105	1,155
			(63.5-65.3)	---	38.9	53.7	7.4	4.3	69.4	1.3	17.1	.6	6,520	11,740	---	.01L	.04	.51			
				---	42.0	58.0	---	4.7	74.9	1.4	18.4	.6	7,040	12,670	---	.01L	.05	.55			
D211795	D	Cook	170.3-178.8	28.4	26.4	39.9	5.3	6.4	49.7	.9	37.4	.4	4,680	8,420	23.0	.02	.04	.38	1,125	1,180	1,230
			(51.9-54.5)	---	36.9	55.7	7.4	4.5	69.4	1.2	16.9	.6	6,540	11,760	---	.02	.05	.53			
				---	39.8	60.2	---	4.8	75.0	1.3	18.2	.7	7,060	12,710	---	.02	.06	.57			
D221116	Q	Cook	155.4-164.0	23.4	27.3	35.9	13.4	5.9	47.3	.9	31.4	1.0	4,540	8,180	17.2	.01	.27	.76	1,215	1,290	1,360
			(47.4-50.0)	---	35.6	46.9	17.5	4.3	61.8	1.2	13.9	1.4	5,930	10,680	---	.01	.36	1.00			
				---	43.1	56.9	---	5.2	74.9	1.5	16.8	1.7	7,750	12,950	---	.01	.43	1.21			
D221123	A	Upper Wall	111.0-143.5	25.0	30.1	40.3	4.6	6.3	52.7	.8	35.2	.3	4,990	8,990	19.8	.01	.06	.25	1,225	1,270	1,340
			(33.5-43.8)	---	40.2	53.6	6.2	4.8	70.3	1.0	17.3	.4	6,660	11,990	---	.01	.07	.33			
				---	42.8	57.2	---	5.1	74.9	1.1	18.5	.4	7,100	17,780	---	.01	.08	.35			
D221124	A	Lower Wall	150.0-155.5	21.6	29.9	41.7	6.8	6.0	53.9	.8	31.8	.7	5,140	9,250	16.7	.01	.17	.54	1,225	1,275	1,325
			(45.8-47.4)	---	38.2	53.2	8.6	4.6	68.7	1.0	16.1	.9	6,550	11,800	---	.01	.22	.68			
				---	41.8	58.2	---	5.1	75.2	1.1	17.6	1.0	7,180	12,920	---	.01	.24	.75			
D221122	B	Upper Wall	339.0-373.0	21.8	29.7	40.6	7.9	5.9	53.1	.8	31.9	.4	5,020	9,040	14.1	.01L	.09	.30	1,030	1,110	1,155
			(103.4-113.8)	---	38.0	51.8	10.2	4.4	67.9	1.0	16.0	.5	6,420	11,550	---	.01L	.12	.39			
				---	42.3	57.7	---	4.9	75.6	1.1	17.8	.6	7,140	12,860	---	.01L	.13	.43			
D211796	D	Upper Wall	226.0-236.0	26.6	27.8	37.9	7.7	6.1	49.1	1.0	35.6	.5	4,680	8,420	21.5	.01	.16	.37	1,070	1,115	1,175
			(68.9-72.0)	---	37.9	51.6	10.5	4.3	67.0	1.3	16.3	.7	6,370	11,470	---	.01	.21	.50			
				---	42.4	57.6	---	4.8	74.8	1.5	18.2	.8	7,120	12,810	---	.01	.24	.56			

Table 4.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, and ash-fusion-temperature determinations for 39 coal samples from Prairie Dog Creek study area, Rosebud County, Montana--Continued

				Proximate analysis				Ultimate analysis					Heat of combustion			Forms of sulfur			Ash-fusion temperature, C°		
Sample No.	Map locality	Coal bed	Depth interval in feet (meters)	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb	Air dried loss	Sulfate	Pyritic	Organic	Initial deformation	Softening	Fluid
D211797	D	Upper Wall	236.0-246.0	26.6	30.4	37.8	5.2	6.4	50.7	0.7	36.7	0.2	4,890	8,800	21.4	0.01	0.03	0.19	1,070	1,150	1,190
			(72.0-75.0)	---	41.4	51.5	7.1	4.6	69.1	1.0	17.8	.3	6,650	11,980	---	.01	.04	.26			
				---	44.6	55.4	---	5.0	74.4	1.1	19.1	.3	7,170	12,900	---	.01	.05	.28			
D211798	D	Upper Wall	246.0-256.0	27.0	31.5	37.9	3.6	6.5	50.9	.7	38.2	.2	5,000	9,000	22.2	.01	.04	.16	1,045	1,090	1,140
			(75.0-78.1)	---	43.1	52.0	4.9	4.8	69.7	1.0	19.4	.3	6,840	12,320	---	.01	.05	.22			
				---	45.3	54.7	---	5.0	73.3	1.0	20.4	.3	7,200	12,960	---	.01	.06	.23			
D211799	D	Upper Wall	256.0-263.5	28.4	29.3	38.7	3.6	6.5	50.4	0.7	38.4	.4	4,880	8,780	23.3	.01	.06	.29	1,120	1,170	1,220
			(78.1-80.4)	---	40.9	54.0	5.1	4.6	70.3	1.0	18.4	.5	6,810	12,260	---	.01	.09	.40			
				---	43.1	56.9	---	4.9	74.1	1.1	19.4	.5	7,180	12,920	---	.01	.09	.43			
D211800	D	Lower Wall	270.1-277.0	28.0	29.4	38.7	3.9	6.4	50.9	.8	37.5	.5	4,900	8,830	22.2	.01	.09	.45	1,095	1,140	1,175
			(82.4-84.5)	---	40.8	53 7	5.5	4.6	70.8	1.1	17.5	.8	6,810	12,260	---	.01	.13	.62			
				---	43.1	56.9	---	6.8	74.8	1.1	18.5	.8	7,200	12,970	---	.01	.14	.65			
D221112	E	Upper Wall	74.3-114.2	25.2	29.5	41.1	4.2	6.3	53.3	.8	34.8	.4	5,070	9,120	17.7	.01	.13	.29	1,140	1,170	1,240
			(22.7-34.8)	---	39.4	54.9	5.7	4.7	71.3	1.1	16.6	.6	6,780	12,200	---	.01	.18	.39			
				---	41.8	58.2	---	5.0	75.6	1.2	17.6	.6	7,180	12,930	---	.01	.19	.41			
D221113	E	Lower Wall	122.0-128.4	20.3	30.5	45.5	3.7	6.1	57.1	1.0	31.6	.5	5,440	9,790	15.4	.01	.09	.41	1,145	1,190	1,250
			(37.2-39.2)	---	38.3	57.1	4.6	4.9	71.7	1.2	17.1	.6	6,820	12,280	---	.01	.12	.51			
				---	40.1	59.9	---	5.1	75.1	1.3	17.9	.7	7,150	12,870	---	.01	.12	.54			
D221107	G	Upper Wall	146.1-185.0	20.7	30.5	43.6	5.2	6.2	55.9	.9	31.5	.3	5,330	9,600	16.2	.01	.08	.23	1,045	1,095	1,155
			(44.6-56.4)	---	38.5	54.9	6.6	4.9	70.4	1.1	16.6	.4	6,720	12,090	---	.01	.10	.29			
				---	41.2	58.8	---	5.3	75.4	1.2	17.8	.4	7,190	12,950	---	.01	.10	.32			
D221108	G	Lower Wall	188.6-195.7	22.0	30.5	42.1	5.4	6.2	54.7	.8	32.2	.7	5,180	9,330	15.9	.01	.17	.52	1,010	1,060	1,115
			(57.5-59.7)	---	39.0	54.1	6.9	4.8	70.1	1.0	16.2	.9	6,640	11,960	---	.01	.22	.67			
				---	42.0	58.0	---	5.1	75.4	1.1	17.5	1.0	7,140	12,850	---	.01	.23	.72			
D221111	I	Wall	267.0-312.2	20.6	29.3	43.4	6.7	6.0	54.7	.9	31.2	.4	5,230	9,420	15.9	.01	.09	.34	1,080	1,155	1,220
			(81.4-95.2)	---	36.9	54.7	8.4	4.7	68.9	1.1	16.2	.6	6,590	11,870	---	.01	.12	.43			
				---	40.3	59.7	---	5.2	75.3	1.2	17.7	.6	7,200	12,960	---	.01	.13	.47			
D221118	K	Wall	135.6-188.4	24.6	30.0	40.2	5.2	6.2	53.1	.8	34.3	.4	5,040	9,070	17.5	.01	.08	.32	1,105	1,145	1,190
			(41.4-57.5)	---	39.8	53.3	6.9	4.6	70.4	1.0	16.5	.5	6,680	12,030	---	.01	.11	.42			
				---	42.8	57.2	---	5.0	75.6	1.1	17.7	.6	7,180	12,920	---	.01	.12	.45			
D221119	K	Wall	190.4-198.8	26.5	28.7	41.1	3.7	6.5	52.4	.8	35.8	.7	5,020	9,040	22.4	.01	.19	.52	1,020	1,070	1,115
			(58.1-60.6)	---	39.1	55.9	5.0	4.9	71.4	1.1	16.7	1.0	6,830	12,300	---	.01	.26	.71			
				---	41.1	58.9	---	5.1	75.1	1.1	17.5	1.0	7,190	12,950	---	.01	.28	.75			
D211788	L	Wall	28.0-38.0	26.8	29.1	38.9	5.2	6.4	51.5	.8	35.6	.5	4,910	8,830	20.2	.01	.10	.42	1,020	1,070	1,130
			(8.5-11.6)	---	39.8	53.0	7.2	4.7	70.4	1.1	16.0	.7	6,700	12,070	---	.01	.13	.57			
				---	42.8	57.2	---	5.0	75.8	1.2	17.2	.8	7,220	12,990	---	.01	.14	.61			
D211789	L	Wall	38.0-48.0	27.0	29.7	39.7	3.6	6.6	52.3	.7	36.4	.3	4,980	8,970	21.5	.05	.05	.15	1,200	1,245	1,295
			(11.6-14.6)	---	40.7	54.3	5.0	5.0	71.6	1.0	17.0	.3	6,830	12,290	---	.08	.06	.20			
				---	42.9	57.1	---	5.3	75.4	1.0	17.9	.4	7,180	12,930	---	.08	.07	.21			
D211790	L	Wall	48.0-58.0	27.6	32.0	37.4	3.0	6.6	52.4	.7	37.1	.2	4,970	8,950	21.6	.01	.02	.17	1,290	1,325	1,365
			(14.6-17.7	---	44.1	51.7	4.2	4.9	72.3	1.0	17.4	.3	6,860	12,350	---	.01	.03	.23			
				---	46.1	53.9	---	5.1	73.4	1.0	18.1	.3	7,160	12,890	---	.01	.03	.24			
D211791	L	Wall	58.0-66.5	27.8	28.1	39.9	4.2	6.5	51.0	.7	37.0	.5	4,870	8,760	23.2	.01	.08	.38	1,125	1,170	1,220
			(17.7-20.3)	---	38.9	55.2	5.9	4.8	70.7	1.0	16.9	.7	6,740	12,140	---	.01	.12	.53			
				---	41.3	58.7	---	5.1	75.1	1.1	18.0	.7	7,170	12,900	---	.01	.12	.57			

Table 4.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, and ash-fusion-temperature determinations for 39 coal samples from Prairie Dog Creek study area, Rosebud County, Montana--Continued

Sample No.	Map local- ity	Coal bed	Depth interval in feet (meters)	Proximate analysis: Mois- ture	Volatile matter	Fixed carbon	Ash	Ultimate analysis: Hydro- gen	Carbon	Nitro- gen	Oxygen	Sulfur	Heat of combustion: Kcal/kg	Btu/lb	Air dried loss	Forms of sulfur: Sul- fate	Pyri- tic	Orga- nic	Ash-fusion temperature, C°: Initial defor- mation	Soften- ing	Fluid
D211792	L	Wall	67.1-74.7	28.9	28.3	39.6	3.2	6.7	51.3	0.8	37.6	0.5	4,900	8,820	21.3	0.02	0.07	0.37	1,110	1,160	1,210
			(20.5-22.8)	---	39.8	55.7	4.5	4.9	72.1	1.1	16.7	.6	6,890	12,400	---	.02	.10	.52			
				---	41.7	58.3	---	5.1	75.5	1.2	17.5	.7	7,210	12,980	---	.02	.10	.55			
D211803	N	Wall	323.0-338.0	25.4	28.8	39.1	6.7	6.3	50.9	.8	34.6	.7	4,850	8,730	20.5	.01	.17	.55	1,170	1,240	1,280
			(98.5-103.1)	---	38.6	52.4	9.0	4.6	68.2	1.0	16.1	1.0	6,490	11,690	---	.01	.22	.73			
				---	42.4	57.6	---	5.1	75.0	1.1	17.7	1.1	7,140	12,850	---	.01	.25	.81			
D211804	N	Wall	338.0-348.0	26.9	28.1	41.5	3.5	6.5	52.2	.7	36.8	.2	4,980	8,970	21.1	.01	.06	.19	1,260	1,295	1,325
			(103.1-106.1)	---	38.4	56.8	4.8	4.8	71.3	1.0	17.7	.3	6,810	12,260	---	.01	.08	.25			
				---	40.3	59.7	---	5.1	75.0	1.0	18.6	.4	7,130	12,890	---	.01	.08	.27			
D211805	N	Wall	348.0-358.0	25.9	31.5	39.4	3.2	6.5	53.1	.7	36.2	.2	5,120	9,220	20.3	.01	.04	.19	1,265	1,310	1,355
			(106.1-109.2)	---	42.4	53.2	4.4	4.9	71.6	1.0	17.8	.3	6,900	12,430	---	.01	.05	.26			
				---	44.4	55.6	---	5.1	74.9	1.0	18.6	.3	7,220	13,000	---	.01	.06	.27			
D211806	N	Wall	358.0-368.0	27.0	29.1	41.1	2.8	6.7	52.8	.8	36.7	.2	5,070	9,130	21.3	.02	.03	.17	1,280	1,330	1,370
			(109.2-112.2)	---	39.9	56.2	3.9	5.0	72.3	1.1	17.3	.3	6,950	12,520	---	.02	.04	.23			
				---	41.5	58.5	---	5.2	75.3	1.2	18.1	.3	7,240	13,030	---	.02	.04	.24			
D211807	N	Wall	368.0-378.0	26.5	29.4	37.9	6.2	6.2	50.4	.8	35.9	.4	4,850	8,740	21.8	.01	.09	.34	1,140	1,205	1,245
			(112.2-115.3)	---	40.0	51.6	8.4	4.5	68.5	1.1	16.9	.6	6,600	11,880	---	.01	.13	.46			
				---	43.7	56.3	---	4.9	74.8	1.2	18.4	.7	7,210	12,970	---	.01	.14	.50			
D211808	N	Wall	378.0-385.4	24.4	29.5	38.5	7.6	6.1	50.5	.9	34.2	.7	4,890	8,810	19.3	.01	.15	.57	1,110	1,160	1,205
			(115.3-117.3)	---	39.0	50.9	10.1	4.5	66.7	1.2	16.6	1.0	6,470	11,640	---	.01	.19	.75			
				---	43.4	56.6	---	5.0	74.2	1.3	18.4	1.1	7,190	12,950	---	.01	.21	.84			
D221117	Q	Wall	244.7-276.2	21.1	31.4	42.6	4.8	6.0	56.3	.9	31.3	.7	5,400	9,720	14.1	.01	.17	.51	1,040	1,100	1,145
			(74.6-84.2)	---	39.9	54.0	6.1	4.7	71.5	1.2	15.7	.9	6,850	12,340	---	.01	.22	.65			
				---	42.5	57.5	---	5.0	76.1	1.3	16.7	.9	7,300	13,140	---	.01	.23	.69			
D221114	E	Carlson	259.5-267.0	16.6	26.1	33.6	23.7	5.1	44.3	.9	24.9	1.2	4,220	7,600	11.7	.01	.34	.81	1,055	1,105	1,145
			(79.1-81.4)	---	31.3	40.3	28.4	3.9	53.1	1.1	12.2	1.4	5,060	9,110	---	.01	.40	.97			
				---	43.7	56.3	---	5.4	74.2	1.5	17.0	1.9	7,070	12,730	---	.01	.56	1.30			
D221115	E	Brewster-Arnold	365.8-376.0	24.4	28.1	39.7	7.8	6.1	51.1	1.0	33.4	.7	4,870	8,760	18.3	.01	.25	.40	1,080	1,130	1,180
			(111.6-114.7)	---	37.1	52.6	10.3	4.5	67.6	1.3	15.5	.9	6,440	11,590	---	.01	.32	.53			
				---	41.4	58.6	---	5.0	75.3	1.4	17.3	1.0	7,180	12,920	---	.01	.36	.59			

Table 5.--Major- and minor-oxide and trace-element composition of the laboratory ash of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[Values in percent or parts per million. Coal ashed at 525° C. L, less than the value shown; N, not detected; B, not determined. S after element title indicates determinations by semiquantitative emission spectrography. The spectrographic results are to be identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as midpoints of the brackets 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, etc. Precision of the spectrographic data is plus-or-minus one bracket at 68-percent or plus-or-minus two brackets at 95-percent confidence level]

Sample number	Ash (percent)	SiO2 (percent)	Al2O3 (percent)	CaO (percent)	MgO (percent)	Na2O (percent)	K2O (percent)	Fe2O3 (percent)	TiO2 (percent)	P2O5 (percent)	Sample number
D221120	5.2	26	9.1	15	5.97	10.4	0.56	5.3	0.47	1.2	D221120
D211793	4.3	17	10	20	11.4	.90	.40	6.6	.37	.23L	D211793
D221109	17.3	58	16	3.8	6.30	1.02	3.2	4.4	.55	.060L	D221109
D211801	4.9	24	10	15	6.30	8.30	.91	5.4	.43	.41	D211801
D211794	26.7	45	19	3.1	1.66	2.20	1.4	12	.62	.71	D211794
D221110	18.3	43	16	2.8	3.81	.66	1.6	19	.57	.11	D221110
D211802	9.8	24	10	6.9	3.98	2.50	.86	24	.37	.31	D211802
D221121	5.9	24	16	14	3.98	10.4	.12	3.0	.45	4.6	D221121
D211795	7.3	32	16	13	1.54	5.00	.23	2.9	.65	1.8	D211795
D221116	13.1	62	9.6	4.6	2.16	.66	.47	4.4	.70	.99	D221116
D221123	5.1	30	15	17	7.13	3.37	.46	4.7	.57	.39	D221123
D221124	7.2	39	12	11	4.31	4.04	.22	5.6	1.1	.56	D221124
D221122	8.8	45	15	8.4	2.32	6.47	1.1	4.9	.78	.45	D221122
D211796	10.6	39	16	8.5	2.16	6.40	.77	6.3	.58	.66	D211796
D211797	7.1	41	12	12	2.82	9.80	.12	3.4	1.2	.56	D211797
D211798	5.4	28	11	14	3.48	11.3	.25	5.3	.55	.37	D211798
D211799	5.1	21	11	14	3.48	11.6	.29	5.7	.50	.20	D211799
D211800	5.4	20	9.6	13	2.98	10.6	.25	7.4	.47	.19L	D211800
D221112	4.7	26	13	14	9.78	1.48	.24	7.2	.55	.21	D221112
D221113	4.2	19	12	17	8.46	1.35	.40	6.7	.45	.24L	D221113
D221107	5.7	32	13	13	2.49	9.84	.30	4.9	.73	.35	D221107
D221108	6.2	36	11	9.4	.02L	8.22	.22	7.2	.73	.16L	D221108
D221111	7.7	43	14	9.0	1.99	6.61	1.1	3.7	.82	.26	D221111
D221118	5.6	30	13	15	4.15	2.97	.35	8.2	.65	.36	D221118
D221119	4.2	15	8.0	12	2.82	12.1	.23	8.7	.37	.24	D221119
D211788	6.9	30	15	15	4.97	1.80	.20	5.4	.55	1.5	D211788
D211789	4.9	26	13	21	6.63	2.70	.20	5.0	.85	.41	D211789
D211790	4.4	24	11	22	6.73	3.10	.12	4.6	.60	.23	D211790
D211791	6.2	26	21	14	4.64	2.40	.23	6.0	.50	.97	D211791
D211792	4.5	20	9.5	17	4.48	7.28	.30	5.3	.47	1.1	D211792
D211803	8.6	36	16	11	4.97	.98	.37	6.0	.67	.58	D211803
D211804	4.5	24	13	21	9.45	2.20	.12	3.7	.82	.22L	D211804
D211805	4.4	24	15	21	8.95	3.00	.24	3.9	.78	.23L	D211805
D211806	4.1	24	11	21	8.79	3.60	.24	3.9	.62	.24L	D211806
D211807	7.3	36	16	11	5.14	2.70	1.2	4.2	.60	1.2	D211807
D211808	8.4	43	14	8.5	3.32	4.50	1.6	5.7	.62	.12L	D211808
D221117	5.4	28	13	12	1.29	9.30	.26	5.9	.57	.93	D221117
D221114	25.7	58	18	2.8	5.64	2.29	3.5	5.0	.62	.080	D221114
D221115	8.5	39	19	7.4	1.11	4.99	.77	6.6	.89	.47	D221115

Table 5.--Major- and minor-oxide and trace-element composition of the laboratory ash of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	La-S (ppm)	Li (ppm)	Sample number
D221120	700	3,000	3	1.0L	500L	84	15	3	30	31	D221120
D211793	1,500	5,000	3	5.0	N	84	50	N	N	26	D211793
D221109	300	1,500	5	1.0L	500L	52	20	7	50	51	D221109
D211801	2,000	10,000	20	4.0	N	88	50	N	N	41	D211801
D211794	200	5,000	10	7.0	N	206	50	20	100L	94	D211794
D221110	300	2,000	10	1.0	500L	233	20	7	70	103	D221110
D211802	700	7,000	20	1.0	N	106	50	N	100L	42	D211802
D221121	700	3,000	7	1.0L	100	75	20	5	70	43	D221121
D211795	1,000	7,000	10	4.0	N	48	50	N	N	38	D211795
D221116	500	2,000	7	1.0	150	84	20	15	70	1	D221116
D221123	700	5,000	2	1.0L	500L	100	20	5	50	61	D221123
D221124	500	5,000	10	1.0L	500L	121	10	5	50	52	D221124
D221122	200	3,000	2	1.0L	500L	100	20	5	50	64	D221122
D211796	500	7,000	3L	5.0	N	89	30	N	100L	87	D211796
D211797	700	15,000	N	10.0	N	109	30	N	N	69	D211797
D211798	1,000	15,000	N	9.0	N	83	30	N	N	47	D211798
D211799	1,000	15,000	5	1.0	N	91	30	N	100L	54	D211799
D211800	1,500	7,000	20	1.0	N	87	50	N	N	36	D211800
D221112	700	5,000	3	1.0L	500L	100	20	5	50	40	D221112
D221113	1,000	7,000	15	1.0L	500L	78	20	2	50	19	D221113
D221107	500	5,000	3	1.0L	500L	82	15	3	50	55	D221107
D221108	700	1,500	10	1.0L	500L	75	15	3	30	40	D221108
D221111	500	3,000	3	1.0L	500L	91	15	3	30	57	D221111
D221118	700	3,000	2	1.0L	500L	93	15	3	50	65	D221118
D221119	700	5,000	10	1.0L	100	97	20	3	30	43	D221119
D211788	700	7,000	3	6.0	N	98	50	N	N	94	D211788
D211789	1,000	7,000	N	32.0	N	131	30	N	N	49	D211789
D211790	1,500	10,000	N	5.0	N	76	30	N	N	24	D211790
D211791	1,000	7,000	5	8.0	N	83	50	N	100L	131	D211791
D211792	1,500	7,000	10	11.0	N	79	30	N	N	37	D211792
D211803	700	7,000	5	2.0	N	113	50	70	100L	102	D211803
D211804	1,500	15,000	N	1.0L	N	105	30	N	N	55	D211804
D211805	1,500	15,000	N	2.0	N	112	30	N	N	55	D211805
D211806	1,500	15,000	N	1.0	N	86	30	N	N	33	D211806
D211807	1,000	7,000	N	1.0	N	92	30	N	N	62	D211807
D211808	1,000	7,000	20	2.0	N	94	70	N	N	40	D211808
D221117	700	3,000	5	1.0L	500L	98	20	15	50	56	D221117
D221114	200	2,000	10	1.0	500L	64	150	20	50	58	D221114
D221115	500	5,000	10	4.0	500L	87	30	7	50	93	D221115

Table 5.--Major- and minor-oxide and trace-element composition of the laboratory ash of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Sample number
D221120	366	15	15	20	99	7	3,000	70	20	1.5	D221120
D211793	437	70	N	50	155	20	3,000	150	70	5	D211793
D221109	204	5	20	50	25L	15	700	100	30	3	D221109
D211801	406	20	N	50	111	30	5,000	150	70	7	D211801
D211794	144	50	N	200	56	30	2,000	500	100	10	D211794
D221110	125	20	20	70	40	20	700	200	70	5	D221110
D211802	297	70	N	200	54	50	2,000	500	150	15	D211802
D221121	287	5	20	50	37	10	10L	15L	30	2	D221121
D211795	146	15	N	30	51	20	7,000	150	100	7	D211795
D221116	95	10	30	30	25L	15	1,500	100	50	5	D221116
D221123	249	7	20	30	47	10	10L	70	30	3	D221123
D221124	247	7	20	50	50	15	3,000	100	20L	5	D221124
D221122	145	5	20	50	100	10	2,000	100	30	3	D221122
D211796	133	10	N	100	79	20	3,000	200	100	7	D211796
D211797	142	7	20	20	63	15	7,000	150	70	5	D211797
D211798	225	N	N	30	207	15	10,000	150	70	5	D211798
D211799	228	10	N	70	136	15	10,000	150	70	5	D211799
D211800	253	50	20L	70	161	50	7,000	150	100	10	D211800
D221112	380	10	15	50	71	10	1,500	70	30	2	D221112
D221113	241	10	20	50	73	20	3,000	100	30	5	D221113
D221107	178	5	15	20	63	10	3,000	70	30	2	D221107
D221108	213	10	20	30	39	15	2,000	50	50	3	D221108
D221111	118	3	15	20	50	10	2,000	70	30	2	D221111
D221118	946	5	20	20	50	10	3,000	70	30	2	D221118
D221119	412	20	15	70	42	15	3,000	15L	50	3	D221119
D211788	144	20	N	100	68	30	5,000	150	70	7	D211788
D211789	189	20	20L	30	130	20	10,000	150	50	5	D211789
D211790	206	7	N	30	56	15	7,000	100	50	5	D211790
D211791	180	70	20	100	49	30	5,000	150	100	7	D211791
D211792	264	30	N	100	59	20	7,000	150	70	7	D211792
D211803	141	20	20	100	88	30	2,000	200	70	7	D211803
D211804	301	10	20L	50	90	20	7,000	150	50	5	D211804
D211805	251	100	20	50	179	20	7,000	150	50	5	D211805
D211806	326	100	20L	50	132	20	10,000	150	50	5	D211806
D211807	254	20	N	50	46	20	5,000	150	50	5	D211807
D211808	256	15	20	100	156	50	3,000	300	100	7	D211808
D221117	157	10	20	30	36	15	5,000	100	50	3	D221117
D221114	144	7	20	50	40	20	1,000	100	30	5	D221114
D221115	270	5	20	30	50	15	3,000	70	30	3	D221115

Table 5.--Major- and minor-oxide and trace-element composition of the laboratory ash of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	Zn (ppm)	Zr-S (ppm)
D221120	102	100
D211793	110	150
D221109	119	200
D211801	75	200
D211794	252	200
D221110	200	300
D211802	117	200
D221121	48	150
D211795	20L	200
D221116	40	500
D221123	76	200
D221124	112	500
D221122	143	200
D211796	82	200
D211797	49	500
D211798	83	300
D211799	85	300
D211800	95	300
D221112	70	150
D221113	141	300
D221107	75	200
D221108	69	200
D221111	67	200
D221118	51	200
D221119	151	200
D211788	135	300
D211789	71	300
D211790	84	300
D211791	190	200
D211792	193	200
D211803	55	300
D211804	53	300
D211805	87	300
D211806	122	300
D211807	126	200
D211808	182	300
D221117	87	200
D221114	90	300
D221115	83	300

Table 6.--Contents of nine trace elements in 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[Analyses in air-dried (32°C) coal, L, less than the value shown]

Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
D221120	0.9	8.8	46	65	0.02	0.2	0.3	0.7	0.6	D221120
D211793	.5	8.8	37	40	.01	.2	.2	.4	.4	D211793
D221109	7.8	24	64	190	.04	.1L	.1L	2.5	.9	D221109
D211801	.9	14	49	55	.04	.4	.4	.6	.5	D211801
D211794	24	30	88	49	.17	1.0	2.3	5.5	5.7	D211794
D221110	61	58	90	150	.27	1.6	2.7	4.4	4.9	D221110
D211802	22	19	61	60	.10	.6	1.2	1.1	1.7	D211802
D221121	.5	16	34	90	.01	.3	.3	1.1	.6	D221121
D211795	.5	7.8	34	65	.02	.2	.6	1.1	.2	D211795
D221116	19	8.9	52	60	.17	.8	1.0	2.2	1.3	D221116
D221123	.8	15	49	110	.03	1.9	.3	.7	.3	D221123
D221124	1.9	32	65	70	.21	.6	.7	1.2	1.0	D221124
D221122	1.4	17	61	75	.09	.3	.6	1.4	.9	D221122
D211796	2.1	15	52	70	.09	.4	.7	1.8	1.3	D211796
D211797	.4	8.3	51	30	.03	.2	.4	1.0	.3	D211797
D211798	.3	7.8	41	25	.02	.1	.1L	.6	.3	D211798
D211799	.7	13	43	20	.03	.1	.4	.7	.5	D211799
D211800	3.9	20	70	30	.05	.4	.3	.6	.4	D211800
D221112	1.8	21	44	30	.06	.2	.5	.6	.4	D221112
D221113	1.0	29	43	30	.04	.1	.3	.4	.2	D221113
D221107	1.6	15	46	45	.09	.2	.6	.9	.4	D221107
D221108	17	31	42	25	.06	.4	.4	.9	.6	D221108
D221111	8.5	11	55	75	.06	.3	.5	1.2	.5	D221111
D221118	.9	13	52	25	.05	.2	.4	.9	.5	D221118
D221119	4.0	64	50	35	.16	.3	.5	.5	.8	D221119
D211788	1.7	12	43	45	.10	.3	.5	1.1	.8	D211788
D211789	.4	12	49	40	.02	.1	.3	.6	.2L	D211789
D211790	.4	9.1	48	35	.02	.1	.2	.5	.2	D211790
D211791	1.9	27	48	45	.06	.4	.6	1.4	1.4	D211791
D211792	.7	38	42	40	.04	1.5	.2	.5	.3	D211792
D211803	5.5	15	65	55	.13	.6	.7	1.8	1.5	D211803
D211804	.4	12	40	50	.02	.1	.2	.5	.3	D211804
D211805	.3	12	2.3L	50	.02	.1	.3	.5	.2L	D211805
D211806	.4	10	49	45	.02	.1	.2	.5	.2	D211806
D211807	1.5	12	64	85	.05	.3	.7	1.5	1.3	D211807
D211808	6.6	20	76	70	.06	.6	.4	1.2	.7	D211808
D221117	1.9	16	48	45	.05	.3	.6	8.1	.7	D221117
D221114	19	14	74	230	.07	1.1	.8	4.0	2.3	D221114
D221115	12	9.8	40	60	.27	.5	.8	1.8	.7	D221115

Table 7.--Major-, minor-, and trace-element composition of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[Values in percent or parts per million, As, Co, Cr, f, Hg, Sb, Se, Th, and U values are from direct determinations on air-dried (32°C) coal; all other values calculated from analyses of coal ash. S means analysis by emission spectrogreaphy; L, less than the value shown; N, not detected; B, not determined]

Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	As (ppm)	B-S (ppm)	Sample number
D221120	0.62	0.25	0.57	0.19	0.40	0.024	0.19	0.015	0.9	30	D221120
D211793	.34	.24	.60	.30	.029	.014	.20	.010	.5	70	D211793
D221109	4.7	1.4	.47	.66	.13	.47	.54	.057	7.8	50	D221109
D211801	.54	.26	.54	.19	.30	.037	.19	.013	.9	100	D211801
D211794	5.6	2.6	.59	.27	.44	.32	2.2	.099	24	50	D211794
D221110	3.7	1.6	.37	.42	.090	.24	2.4	.062	61	70	D221110
D211802	1.1	.54	.48	.23	.18	.070	1.7	.022	22	70	D211802
D221121	.65	.50	.59	.14	.45	.006	.12	.016	.5	30	D221121
D211795	1.1	.61	.66	.068	.27	.014	.15	.028	.5	70	D211795
D221116	3.8	.67	.43	.17	.064	.051	.41	.055	19	50	D221116
D221123	.71	.41	.61	.22	.13	.020	.17	.017	.8	30	D221123
D221124	1.3	.45	.59	.19	.22	.013	.28	.045	1.9	30	D221124
D221122	1.8	.70	.53	.12	.42	.083	.30	.041	1.4	20	D221122
D211796	1.9	.88	.65	.14	.50	.068	.47	.037	2.1	50	D211796
D211797	1.3	.45	.63	.12	.52	.007	.17	.051	.4	50	D211797
D211798	.70	.32	.54	.11	.45	.011	.20	.018	.3	50	D211798
D211799	.51	.29	.51	.11	.44	.012	.20	.015	.7	50	D211799
D211800	.50	.28	.51	.097	.42	.011	.28	.015	3.9	70	D211800
D221112	.56	.32	.47	.28	.052	.009	.23	.015	1.8	30	D221112
D221113	.37	.26	.50	.21	.042	.014	.20	.011	1.0	30	D221113
D221107	.85	.39	.51	.085	.42	.014	.19	.025	1.6	30	D221107
D221108	1.1	.35	.42	.001L	.38	.011	.31	.027	17	50	D221108
D221111	1.5	.57	.49	.092	.38	.069	.20	.038	8.5	30	D221111
D221118	.78	.39	.62	.14	.12	.016	.32	.022	.9	30	D221118
D221119	.29	.18	.36	.071	.38	.008	.26	.009	4.0	30	D221119
D211788	.97	.55	.76	.21	.092	.012	.26	.023	1.7	50	D211788
D211789	.59	.35	.73	.20	.098	.008	.17	.025	.4	50	D211789
D211790	.48	.25	.70	.18	.10	.004	.14	.016	.4	70	D211790
D211791	.74	.68	.62	.17	.11	.012	.26	.019	1.9	70	D211791
D211792	.42	.22	.54	.12	.24	.011	.17	.013	.7	70	D211792
D211803	1.5	.71	.65	.26	.062	.027	.36	.035	5.5	70	D211803
D211804	.49	.31	.67	.26	.073	.005	.12	.022	.4	70	D211804
D211805	.48	.34	.66	.24	.098	.009	.12	.021	.3	70	D211805
D211806	.45	.24	.61	.22	.11	.008	.11	.015	.4	70	D211806
D211807	1.2	.62	.60	.23	.15	.070	.21	.026	1.5	70	D211807
D211808	1.7	.60	.51	.17	.28	.11	.34	.031	6.6	100	D211808
D221117	.70	.36	.45	.042	.37	.012	.22	.018	1.9	50	D221117
D221114	6.9	2.4	.51	.87	.44	.75	.90	.095	19	70	D221114
D221115	1.5	.83	.45	.057	.31	.055	.39	.045	12	50	D221115

Table 7.--Major-, minor-, and trace-element composition of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Ge-S (ppm)	Sample number
D221120	150	0.15	0.05L	20L	8.8	46	4.4	65	0.7	0.15	D221120
D211793	200	.15	.22	N	8.8	37	3.6	40	2	N	D211793
D221109	200	1	.17L	100L	24	64	9.0	190	3	1	D221109
D211801	500	1	.20	N	14	49	4.3	55	2	N	D211801
D211794	1,500	3	1.9	N	30	88	55	49	15	5	D211794
D221110	500	2	.18	100L	58	90	43	150	5	1.5	D221110
D211802	700	2	.10	N	19	61	10	60	5	N	D211802
D221121	200	.3	.06L	5	16	34	4.4	90	1.5	.2	D221121
D211795	500	.7	.29	N	7.8	34	3.5	65	3	N	D211795
D221116	300	1	.13	15	8.9	52	11	60	2	2	D221116
D221123	200	.15	.05L	20L	15	49	5.1	110	1.5	.2	D221123
D221124	300	.7	.07L	30L	32	65	8.7	70	1	.3	D221124
D221122	300	.2	.09L	50L	17	61	8.8	75	2	.5	D221122
D211796	700	.3L	.53	N	15	52	9.4	70	3	N	D211796
D211797	1,000	N	.71	N	8.3	51	7.7	30	2	N	D211797
D211798	700	N	.49	N	7.8	41	4.5	25	1.5	N	D211798
D211799	700	.2	.05	N	13	43	4.6	20	1.5	N	D211799
D211800	300	1	.05	N	20	70	4.7	30	3	N	D211800
D221112	200	.15	.05L	20L	21	44	4.7	30	1	.2	D221112
D221113	300	.5	.04L	20L	29	43	3.3	30	1	.1	D221113
D221107	300	.2	.06L	30L	15	46	4.7	45	1	.15	D221107
D221108	100	.7	.06L	30L	31	42	4.7	25	1	.2	D221108
D221111	200	.2	.08L	50L	11	55	7.0	75	1	.3	D221111
D221118	200	.15	.06L	30L	13	52	5.2	25	.7	.2	D221118
D221119	150	.5	.04L	5	64	50	4.1	35	1	.15	D221119
D211788	500	.2	.41	N	12	43	6.8	45	3	N	D211788
D211789	300	N	1.6	N	12	49	6.4	40	1.5	N	D211789
D211790	500	N	.22	N	9.1	48	3.3	35	1.5	N	D211790
D211791	500	.3	.50	N	27	48	5.1	45	3	N	D211791
D211792	300	.5	.50	N	38	42	3.6	40	1.5	N	D211792
D211803	700	.5	.17	N	15	65	9.7	55	5	7	D211803
D211804	700	N	.05L	N	12	40	4.7	50	1.5	N	D211804
D211805	700	N	.09	N	12	2.3L	4.9	50	1.5	N	D211805
D211806	700	N	.04	N	10	49	3.5	45	1.5	N	D211806
D211807	500	N	.07	N	12	64	6.7	85	2	N	D211807
D211808	700	1.5	.17	N	20	76	7.9	70	7	N	D211808
D221117	200	.3	.05L	30L	16	48	5.3	45	1.5	.7	D221117
D221114	700	2	.26	150L	14	74	16	230	30	5L	D221114
D221115	500	1	.34	50L	9.8	40	7.4	60	3	.5	D221115

Table 7.--Major-, minor-, and trace-element composition of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	Hg (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sb (ppm)	Sample number
D221120	0.02	1.5	1.6	19	0.7	0.7	1	260	5.1	0.2	D221120
D211793	.01	N	1.1	19	3	N	2	43L	6.7	.2	D211793
D221109	.04	10	8.8	35	.7	3	7	45L	4.3L	.1L	D221109
D211801	.04	N	2.0	20	1	N	2	88	5.4	.4	D211801
D211794	.17	30L	25	38	15	N	50	830	15	1.0	D211794
D221110	.27	15	19	23	5	5	15	88	7.3	1.6	D221110
D211802	.10	10L	4.1	29	7	N	20	130	5.3	.6	D211802
D221121	.01	3	2.5	17	.3	1	3	1,200	2.2	.3	D221121
D211795	.02	N	2.8	11	1	N	2	570	3.7	.2	D211795
D221116	.17	7	.1	12	1.5	5	5	570	3.3L	.8	D221116
D221123	.03	2	3.1	13	.3	1.5	1.5	87	2.4	1.9	D221123
D221124	.21	3	3.7	18	.5	1.5	3	180	3.6	.6	D221124
D221122	.09	5	5.6	13	.5	2	3	170	8.8	.3	D221122
D211796	.09	10L	9.2	14	1	N	10	310	8.4	.4	D211796
D211797	.03	N	4.9	10	.5	1.5	1.5	170	4.5	.2	D211797
D211798	.02	N	2.5	12	N	N	1.5	87	11	.1	D211798
D211799	.03	5L	2.8	12	.5	N	3	45	6.9	.1	D211799
D211800	.05	N	1.9	14	3	1L	3	45L	8.7	.4	D211800
D221112	.06	2	1.9	18	.5	.7	2	43	3.3	.2	D221112
D221113	.04	2	.8	10	.5	1	1.5	44L	3.1	.1	D221113
D221107	.09	2	3.1	10	.3	1	1.5	87	3.6	.2	D221107
D221108	.06	2	2.5	13	.5	1	2	43L	2.4	.4	D221108
D221111	.06	3	4.4	9.1	.3	1.5	1.5	87	3.9	.3	D221111
D221118	.05	2	3.6	53	.3	1	1.5	88	2.8	.2	D221118
D221119	.16	1.5	1.8	17	1	.7	3	44	1.8	.3	D221119
D211788	.10	N	6.5	9.9	1.5	N	7	440	4.7	.3	D211788
D211789	.02	N	2.4	9.3	1	1L	1.5	88	6.4	.1	D211789
D211790	.02	N	1.1	9.1	.3	N	1.5	44	2.5	.1	D211790
D211791	.06	7L	8.1	11	5	1.5	7	260	3.0	.4	D211791
D211792	.04	N	1.7	12	1.5	N	5	220	2.7	1.5	D211792
D211803	.13	10L	8.8	12	1.5	1.5	10	220	7.6	.6	D211803
D211804	.02	N	2.5	14	.5	1L	2	43L	4.1	.1	D211804
D211805	.02	N	2.4	11	5	1	2	44L	7.9	.1	D211805
D211806	.02	N	1.4	13	5	.7L	2	43L	5.4	.1	D211806
D211807	.05	N	4.5	19	1.5	N	3	390	3.4	.3	D211807
D211808	.06	N	3.4	22	1.5	1.5	10	44L	13	.6	D211808
D221117	.05	3	3.0	8.5	.5	1	2	220	1.9	.3	D221117
D221114	.07	10	15	37	1.5	7	10	90	10	1.1	D221114
D221115	.27	5	7.9	23	.5	1.5	2	170	4.3	.5	D221115

Table 7.--Major-, minor-, and trace-element composition of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--continued

Sample number	Sc-S (ppm)	Se (ppm)	Sr-S (ppm)	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)	Sample number
D221120	0.3	0.3	150	0.7	0.6	3	1.5	0.07	5.3	7	D221120
D211793	1	.2	150	.4	.4	7	3	.2	4.7	7	D211793
D221109	3	.1L	100	2.5	.9	15	7	.7	21	30	D221109
D211801	1.5	.4	200	.6	.5	7	3	.3	3.7	10	D211801
D211794	7	2.3	500	5.5	5.7	150	30	3	67	50	D211794
D221110	5	2.7	100	4.4	4.9	30	10	1	37	50	D221110
D211802	5	1.2	200	1.1	1.7	50	15	1.5	11	20	D211802
D221121	.7	.3	.7L	1.1	.6	1L	2	.15	2.8	7	D221121
D211795	1.5	.6	500	1.1	.2	10	7	.5	1.5L	15	D211795
D221116	2	1.0	200	2.2	1.3	15	7	.7	5.2	70	D221116
D221123	.5	.3	.5L	.7	.3	3	1.5	.15	3.9	10	D221123
D221124	1.5	.7	200	1.2	1.0	7	1.5L	.3	8.1	30	D221124
D221122	1	.6	200	1.4	.9	10	3	.3	13	15	D221122
D211796	2	.7	300	1.8	1.3	20	10	.7	8.7	20	D211796
D211797	1	.4	500	1.0	.3	10	5	.3	3.5	30	D211797
D211798	.7	.1L	500	.6	.3	7	3	.3	4.5	15	D211798
D211799	.7	.4	500	.7	.5	7	3	.2	4.3	15	D211799
D211800	3	.3	300	.6	.4	7	5	.5	5.1	15	D211800
D221112	.7	.5	70	.6	.4	3	1.5	.1	3.3	7	D221112
D221113	1	.3	150	.4	.2	5	1.5	.2	5.9	10	D221113
D221107	.7	.6	200	.9	.4	3	2	.15	4.3	10	D221107
D221108	1	.4	150	.9	.6	3	3	.2	4.3	15	D221108
D221111	.7	.5	200	1.2	.5	7	2	.2	5.2	20	D221111
D221118	.5	.4	150	.9	.5	5	1.5	.1	2.9	10	D221118
D221119	.7	.5	150	.5	.8	.7L	2	.15	6.3	10	D221119
D211788	2	.5	300	1.1	.8	10	5	.5	9.3	20	D211788
D211789	1	.3	500	.6	.2L	7	2	.2	3.5	15	D211789
D211790	.7	.2	300	.5	.2	5	2	.2	3.7	15	D211790
D211791	2	.6	300	1.4	1.4	10	7	.5	12	15	D211791
D211792	1	.2	300	.5	.3	7	3	.3	8.7	10	D211792
D211803	2	.7	150	1.8	1.5	15	7	.7	4.7	20	D211803
D211804	1	.2	300	.5	.3	7	2	.2	2.4	15	D211804
D211805	1	.3	300	.5	.2L	7	2	.2	3.8	15	D211805
D211806	.7	.2	500	.5	.2	7	2	.2	5.0	15	D211806
D211807	1.5	.7	300	1.5	1.3	10	3	.3	9.2	15	D211807
D211808	5	.4	200	1.2	.7	20	10	.7	15	20	D211808
D221117	.7	.6	200	8.1	.7	7	2	.15	4.7	15	D221117
D221114	5	.8	200	4.0	2.3	30	10	1	23	70	D221114
D221115	1	.8	200	1.8	.7	7	3	.3	7.1	30	D221115

Table 8.--Elements looked for but not detected in 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[Approximate lower detection limits for these elements in ash, by the six-step spectrographic method of the U.S. Geological survey, are included]

Element name	Symbol	Lower limit of detection (ppm) in ash
Silver	Ag	1
Gold	Au	50
Bismuth	Bi	20
Dysprosium	Dy	100
Erbium	Er	100
Europium	Eu	200
Gadolinium	Gd	100
Hafnium	Hf	200
Holmium	Ho	50
Indium	In	20
Lutetium	Lu	70
Palladium	Pd	5
Praseodymium	Pr	200
Platinum	Pt	100
Rhenium	Re	100
Samarium	Sm	200
Tin	Sn	20
Tantalum	Ta	1,000
Terbium	Tb	700
Tellerium	Te	5,000
Thallium	Tl	100
Thulium	Tm	50
Tungsten	W	200

Table 9.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat of combustion, forms of sulfur, and ash-fusion temperatures of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[For comparison, geometric means for 33 Powder River region coal samples are included (Swanson and others, 1976, tables 31b and 32b). All values are in percent except Kcal/kg, Btu/lb, ash-fusion temperatures, and geometric deviations, and are reportedon the as-received basis. L, less than the value shown. Leaders (---) indicate no data. $^{o}F = (^{o}C \times 1.8) + 32$]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
Proximate and ultimate analyses						
Moisture	25.2	16.6	30.6	25.0	1.1	23.1
Volatile matter	28.9	25.1	32.0	28.9	1.1	32
Fixed carbon	39.3	30.6	45.5	39.2	1.1	36
Ash	6.4	2.8	23.7	5.5	1.7	7.5
Hydrogen	6.2	5.1	6.7	6.2	1.1	6.2
Carbon	51.0	40.0	57.1	50.9	1.1	50.3
Nitrogen	.8	.7	1.1	.8	1.1	.9
Oxygen	38.5	.6	39.4	31.1	1.9	32.9
Sulfur	.6	.2	3.2	.5	1.9	.8
Heat of combustion						
Kcal/kg	4,875	3,885	5,445	4,870	1.1	4,860
Btu/lb	8,770	6,990	9,790	8,760	1.1	8,740
Forms of sulfur						
Sulfate	0.02	0.01L	0.26	0.01	2.3	0.02
Pyritic	.17	.02	1.91	.10	2.7	.29
Organic	.43	.15	1.17	.37	1.7	.31
Ash-fusion temperatures, °C						
Initial deformation	1,120	1,010	1,290	1,120	1.1	---
Softening temperature	1,170	1,060	1,350	1,170	1.1	---
Fluid temperature	1,220	1,120	1,390	1,220	1.1	---

Table 10.--Arithmetic mean, observed range, geometric mean, and geometric deviation of ash content and contents of nine major and minor oxides in the laboratory ash of 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[For comparison, geometric means for 410 Powder Riover region samples are included (Hatch and Swanson, 1977, table 6a). All samples were ashed at 525^{o}C; all analyses except geometric deviation are in percent. L, less than the value shown. Leaders (---) indicate no data]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
(Ash)	7.8	4.1	26.7	6.9	1.6	9.0
SiO_2	32	15	62	30	1.4	28
Al_2O_3	13	8.0	21	13	1.3	14
CaO	13	2.8	22	11	1.7	15
MgO	4.8	1.1L	11	3.9	1.9	3.6
Na_2O	5.4	.66	12	3.7	2.4	.93
K_2O	.62	.12	3.5	.42	2.4	.28
Fe_2O_3	6.2	2.9	24	5.7	1.5	5.8
TiO_2	.62	.37	1.2	.60	1.3	.61
P_2O_5	.68	.08L	4.6	.28	3.9	---

Table 11.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 39 elements in 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana

[For comparison, geometric means for 410 Powder River region coal samples are included (Hatch and Swanson, 1977, table 6b). All analyses except geometric deviation are in percent or parts per million and are reported on a whole-coal basis. As, Co, Cr, F, Hg, Sb, Se, Th, and U values used to calculate the statistics were determined directly on whole coal. All other values used were calculated from determinations made on coal ash. L, less than the value shown. Leaders (---) indicate no data]

Element	Arithmetic mean	Observed range: Minimum	Observed range: Maximum	Geometric mean	Geometric deviation	Powder River region geometric mean
			Percent			
Si	1.3	0.29	6.9	.97	2.2	1.2
Al	.58	.18	2.6	.47	1.9	.66
Ca	.56	.36	.75	.55	1.2	.98
Mg	.201	.041L	.87	.16	1.9	.20
Na	.27	.028	.52	.19	2.3	.063
K	.054	.004	.75	.024	3.6	.022
Fe	.36	.11	2.4	.27	2.1	.37
Ti	.030	.009	.099	.024	1.8	.035
P	.020	.004L	.12	.010	3.3	---
			Parts per million			
As	5.6	0.3	61	1.9	4.3	2
B	50	20	100	50	1.5	50
Ba	500	100	1500	500	1.9	300
Be	.7	.3L	3	.3	3.2	.5
Cd	.3	.04L	1.8	.07	5.6	.04
Co	18	7.7	64	15	1.7	2
Cr	52	33	90	50	1.3	5
Cu	7.7	3.3	55	6.4	1.8	9.5
F	60	20	230	52	1.7	40
Ga	3	.7	30	2	2.2	2
Ge	.5	.1L	7	.1	7.2	---
Hg	.07	.01	.27	.05	2.4	.08
La	2	1.5L	15	1.5	3.1	---
Li	4.9	.1	25	3.2	2.6	3.9
Mn	17	8.4	52	15	1.6	34
Mo	1.5	.3L	15	1	2.9	1.5
Nb	1.5	.7L	7	1	2.5	1.0
Ni	5	1	50	3	2.4	3
Pb	5.3	1.7L	14	4.4	1.8	5.1
Sb	.4	.1L	1.9	.3	2.6	.4

Table 11.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 39 elements in 39 coal samples from the Fort Union Formation, Prairie Dog Creek study area, Rosebud County, Montana--Continued

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
		Parts per million				
Sc	1.5	0.3	7	1.5	2.1	1.5
Se	.6	.2L	2.7	.4	2.0	.7
Sr	300	.7L	500	150	2.2	150
Th	1.4	.4	8.1	1.1	2.1	3.3
U	.9	.2L	5.7	.6	2.4	.6
V	15	3L	150	7	2.3	10
Y	5	1.5L	30	3	2.2	3
Yb	.5	.07	3	.3	2.2	.3
Zn	8.4	2.4L	67	6.3	2.1	12.5
Zr	20	7	70	15	1.8	15

To be consistent with the precision of the semiquantitative emission spectrographic technique, arithmetic and geometric means of elements determined by this method are reported as the midpoints of the enclosing six-step brackets. For an explanation of six-step brackets, see headnote of table 5, or see Swanson and Huffman, 1976, p. 6.

Explanation of statistical terms used in summary tables

In this report the geometric mean (GM) is used as the estimate of the most probable concentration (mode); the geometric mean is calculated by taking the logarithm of each analytical value, summing the logarithms, dividing the sum by the total number of values, and obtaining the antilogarithm of the result. The measure of scatter about the mode used here is the geometric deviation (GD), which is the antilog of the standard deviation of the logarithms of the analytical values. These statistics are used because the quantities of trace elements in natural materials commonly exhibit positively skewed frequency distributions; such distributions are normalized by analyzing and summarizing trace-element data on a logarithmic basis.

If the frequency distributions are lognormal, the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to GM$\cdot$GD. The estimated range of the central 95 percent of the observed distribution has a lower limit equal to GM/GD^2 and an upper limit equal to GM$\cdot$GD^2 (Connor and others, 1976).

Although the geometric mean is, in general, an adequate estimate of the most common analytical value, it is, nevertheless, a biased estimation of the arithmetic mean. The estimates of the arithmetic means listed in the summary tables are Sichel's _t_ statistic (Miesch, 1967).

A common problem in statistical summaries of trace-element data arises when the element content of one or more of the samples is below the limit of analytical detection. This results in a "censored" distribution. Procedures developed by Cohen (1959) were used to compute unbiased estimates of the geometric mean, geometric deviation, and arithmetic mean when the data were censored.

Regional statistical comparison of composition of Prairie Dog Creek coal

Using the geometric means shown in tables 9, 10, and 11, the analytical data from the 39 samples of coal from the Prairie Dog Creek study area can be compared statistically with analytical data from coal beds in the surrounding Powder River region of Montana and Wyoming. The following comparisons use the student's t test at the 95-percent confidence level.

Coal from the Prairie Dog Creek study area has significantly higher contents of moisture and fixed carbon, and significantly lower contents of volatile matter, ash, nitrogen, total sulfur, sulfate sulfur, and pyritic sulfur than coal from 33 regional samples (table 9). The heat of combustion and the contents of hydrogen, carbon, oxygen, and organic sulfur are not significantly different. When compared at the 99-percent confidence level, the contents of moisture, nitrogen, and sulfur are not significantly different.

Coal from the Prairie Dog Creek study area has significantly higher contents of Na_2O and K_2O, and significantly lower contents of ash and CaO content in the ash than coal from 410 regional samples (table 10). The contents of SiO_2, Al_2O_3, MgO, Fe_2O_3, and TiO_2 are not significantly different. When compared at the 99-percent confidence level, the content of K_2O is not significantly different.

Coal from the Prairie Dog Creek study area has significantly higher contents of Na, Ba, Cd, Co, Cr, and F, and significantly lower contents of Al, Ca, Mg, Fe, Ti, Be, Cu, Hg, Mn, Se, Th, V, and Zn than coal from 410 regional samples (table 11). The contents of Si, K, As, B, Ga, Li, Mo, Nb, Ni, Pb, Sb, Sc, Sr, U, Y, Yb, and Zr are not significantly different. When compared at the 99-percent confidence level, the contents of Fe and F are not significantly different.

Differences in the oxide composition of coal ashes and the elemental contents of coal result from differences in the total and relative amounts of the various inorganic minerals, the elemental composition of these minerals, and the total and relative amounts of any organically bound elements. The chemical form and distribution of a given element are dependent on the geologic history of the coal bed. A partial listing of the factors that influence element distributions would include chemical composition of original plants; amounts and composition of the various detrital, diagenetic, and epigenetic minerals; chemical characteristics of the ground waters that come in contact with the bed; temperatures and pressures during burial; and extent of weathering. No evaluation of these factors has been made for coal from the Prairie Dog Creek study area.

Composition of Prairie Dog Creek coals, by bed

The 39 samples of coal were taken from six coal beds in the Prairie Dog Creek study area. Twenty-seven samples are from the Wall bed, and, of these, 16 samples were taken from three localities (D, L, and N) at which the Wall was sampled in detail to determine variations of composition within the coal bed (fig. 2). On the average, the Wall coal is low in sulfur and ash (table 12) and has a heating value of 9200 Btu/lb (5210 kcal/kg) on an as-received basis. When calculated on a moist-mineral-matter-free basis, the heating value indicates an apparent rank for the Wall bed of subbituminous B. The detailed sampling of the bed indicates that the middle part of the Wall is remarkably low in sulfur and ash content, being about 0.2 percent sulfur and 3 percent ash on an as-received basis. The uppermost and lowermost samples have a sulfur content of 0.5 to 0.7 percent and an ash content ranging from 3.2 to 6.7 percent. The heating value of individual samples ranges from 8420 to 9790 Btu/lb (4770 to 5510 kcal/kg) on an as-received basis. The highest heating values for the bed as a whole are in the south and east (localities Q, G, and I).

Four analyses of the Canyon coal bed (table 4) show a sulfur content of 0.4 to 0.5 percent, a variable ash content ranging from 3.2 to 15.4 percent, and a heating value ranging from 7850 to 8550 Btu/lb (4450 to 4840 kcal/kg) on an as-received basis. Its apparent rank is subbituminous C.

Table 12.--Average heat of combustion, moisture, ash and sulfur content on an as-received basis, and apparent rank, by 39 coal bed, of coal samples from the Prairie Dog Creek study area, Rosebud County, Montana

[To convert Btu/lb to Kcal/kg divide by 1.8]

Coal bed	No. of samples	Moisture	Ash	Sulfur	Heat-of-combustion Btu/lb.	Moist mineral matter-free heat content	Apparent coal rank
Canyon	4	27.6	6.6	.5	8,360	9,020	Subbituminous C
Sub Canyon	3	24.4	13.5	2.7	7,720	9,100	Do.
Cook	3	26.4	8.0	.6	8,380	9,190	Do.
Wall	15	24.2	4.9	.5	9,200	9,730	Subbituminous B
Upper Wall	8	24.0	5.4	.3	9,100	9,680	Do.
Lower Wall	4	23.0	5.0	.6	9,300	9,850	Do.
Carlson	1	16.6	23.7	1.2	7,600	10,300	Do.
Brewster-Arnold	1	24.4	7.8	.7	8,760	9,590	Do.

Two samples of the Cook coal bed show a low sulfur and low ash content of 0.4 and 5.4 percent respectively, but the third sample is relatively high in ash and moderate in sulfur (table 4). The sub-Canyon bed has a relatively high ash content of 13.5 percent, a moderate sulfur content of 2.7 percent, and an apparent rank of subbituminous C, according to the as-received analyses of three samples.

The single samples of two of the beds (fig. 1) below the Wall show a high ash and moderate sulfur content for the Carlson, and a moderate ash and low sulfur content for the Brewster-Arnold on an as-received basis. The apparent rank, however, is subbituminous B for both beds.

Estimation and classification of coal resources

In preparing the coal resource estimates for the Prairie Dog Creek study area, the procedures and definitions used were those of the Coal Resources Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey (1976), which is published as U.S. Geological Survey Bulletin 1450-B.

The term "coal resources," as used herein, designates the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible. Identified resources are specific bodies of coal whose location, rank, quality, and quantity are known from geologic evidence supported by engineering measurements.

Tabulation of coal resources

In the study area, identified coal resources that have potential for recovery by surface mining methods are assumed to be coal within 200 feet (60 m) of the surface for the Canyon bed, or within 500 feet of the surface for the thick Wall bed. As such, these coal resources fall into a category called reserve base, which is defined as that part of the identified coal resource from which reserves are calculated. Reserves are the actual amount of coal that can be economically mined from a deposit at the time of determination considering all legal, technological, and environmental restraints, and they are derived by applying a percent recovery factor to the reserve base. The recovery factor takes into account all coal remaining in the ground after mining is completed (considered to be "lost in mining") and includes coal (1) left unmined beneath rivers, lakes, highways, and legal reservations; (2) left unmined adjacent to mine or property boundaries; or (3) left unmined because of environmental, quality, safety, hydrologic, or legal restrictions.

In the United States, the recovery factor for surface mining methods locally exceeds 90 percent. Because of the many uncertainties about legal and other restrictions on surface mining, no recovery factor was applied to the reserve base coal in the study area.

Characteristics used in resource evaluation

The characteristics used in evaluating resources can be divided into two main classes: (1) those that affect the utilization and the economic feasibility of recovery of coal, and (2) those that characterize the coal resources in terms of the degree of geologic assurance that the coal resources exist in the amount stated. Such factors as rank, grade, and density of the coal, and the depth and thickness of the bed affect the economic feasibility of recovery and utilization of the coal. The rank and the grade of the coal in the study area have been discussed previously.

Density

The density, or weight per unit volume, of the coal varies considerably with differences in rank and ash content. In the Prairie Dog Creek study area, the density or specific gravity of the coals has not been determined so an average density or specific gravity is used, based on determinations from other areas. For subbituminous coal the average density is taken as 1,770 short tons per acre-foot, and the average specific gravity as 1.30.

Thickness of coal beds

Because of the importance of the thickness of the coal in determining the economic feasibility of recovery, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. For subbituminous coal the categories are (1) thin, 2.5-5 feet (0.75-1.5 m), (2) intermediate, 5-10 feet (1.5-3 m), and (3) thick, more than 10 feet (3 m). In the Prairie Dog Creek study area, all of the resources tabulated in the Wall coal bed are in the thick category, the resources for the Canyon coal bed are both intermediate and thick, and the resources in the Cook bed are intermediate and thin (pls. 2, 3, and 4).

Depth of coal beds

Coal resources are commonly divided into categories based on the depth of the coal bed, as follows: 0-1,000 feet (0-300 m), 1,000-2,000 feet (300-600 m), 2,000-3,000 feet (600-900 m), and 3,000-6,000 feet (900-1,800 m). Additional categories of depth for coal resources that can be recovered by surface mining methods are not standardized, because of the many factors that affect the amount of overburden that can be economically removed from a coal deposit. In this area it is assumed that the Canyon and Cook coal beds to a depth of 200 feet (61 m) and the Wall bed to a depth of 500 feet (152 m) can be economically mined by surface-mining methods.

Resource categories according to degree of geologic assurance

The coal resources tabulated for the Prairie Dog Creek study area are all in the "Identified" category of geologic assurance, and are subdivided into "Measured," "Indicated," and "Inferred" categories according to the nearness of the coal to a measurement of the coal bed, and on geologic evidence and projection.

Measured -- Coal for which estimates of the rank, quality, and quantity have been computed, with a margin of error of less than 20 percent, from sample analyses and measurements from closely spaced and geologically well-known sample sites. In this area measured coal is within 1/4 mile (0.4 km) of a measurement in a drill hole or outcrop.

Indicated-- Coal for which estimates of the rank, quality, and quantity have been computed partly from sample analysis and measurements and partly from reasonable geologic projections. In this area, indicated coal is the body of coal whose inner limit is 1/4 mile (0.4 km) from a measurement in a drill hole or outcrop and whose outer limit is 3/4 mile (1.2 km) from the measurement.

Inferred -- Coal in unexplored extensions of indicated resources for which estimates of the quality and size are based on geologic evidence and projection. In this area, inferred coal lies more than 3/4 mile (1.2 km) from a measurement in a drill hole or outcrop, but not more than 3 miles (4.8 km).

Demonstrated--A collective term for the sum of coal in both measured and indicated resources and reserves.

Summary of coal resources

The Wall coal bed contains 360 million short tons (327 million metric tons) of potentially surface-minable subbituminous B coal under less than 200 feet (61 m) of overburden, and an additional 284 million tons (258 million metric tons) under 200-500 feet (61-152 m) of overburden (table 13). The coal ranges in thickness from 31.5 to 62.5 feet (9.6 to 19.1 m), excluding all partings. The coal thickness includes Upper and Lower Wall where the Wall is separated into two beds. About 73 percent of the total Wall coal resources is Demonstrated reserve base; the remainder is Inferred reserve base.

The thinnest of the three beds, the Cook, contains a total of 25.9 million short tons (23.5 million metric tons) where the overburden is less than 200 feet (61 m) thick. The coal ranges in thickness from 2.1 to 8.6 feet (0.6 to 2.6 m) but no resources were calculated for thicknesses less than 2.5 feet (0.8 m). About 65 percent of the resources are in the "thin" category of 2.5 to 5.0 feet (0.8 to 1.5 m).

The Canyon coal bed, which is 4.5 to 15.5 feet (1.4 to 4.7 m) thick, contains 35.3 million short tons (32 million metric tons) of subbituminous C coal under less than 200 feet (61 m) of overburden (table 13). Of this amount, 65 percent is classified as Demonstrated reserve base and the remainder is Inferred reserve base. About one-third is in coal more than 10 feet (3 m) thick, mainly in the northwest part of the study area.

The Cook and Canyon are locally valuable as individual beds, and their occurrence within practical mining distance of the Wall provides incentive to mine the Wall under thick overburden. If 500 feet (153 m) of overburden were removed from the Wall, the tabulated resources of the Wall, Cook, and Canyon

Table 13.--Identified resources of potentially surface-minable coal in three beds in the Fort Union Formation, Prairie Dog Creek study area, T. 6 S., R. 41 E., Rosebud County, Montana, as of 1/1/80

[In millions of short tons. 1 short ton = 0.907 metric tons; 1 ft = 0.305 m. Totals rounded to three significant figures. Leaders (---) indicate no data]

	Demonstrated									
	Measured			Indicated			Inferred			
	Coal thickness in feet			Coal thickness in feet			Coal thickness in feet			
Coal Bed	2.5-5	5-10	>10	2.5-5	5-10	>10	2.5-5	5-10	>10	Total
0-200 feet of overburden										
Canyon	.13	2.95	1.61	---	13.9	4.55	---	6.42	5.88	35.3
Cook	4.55	2.47	---	8.33	5.51	---	3.96	1.12	---	25.9
Wall	---	---	83.7	---	---	199.	---	---	77.0	360.
Total	4.68	5.42	85.3	8.33	19.4	204.	3.96	7.54	82.9	421.
200-500 feet of overburden										
Wall	---	---	29.6	---	---	159.	---	---	95.8	284.
Total	---	---	29.6	---	---	159.	---	---	95.8	284.
Grand total	4.68	5.42	115.	8.33	19.4	363.	3.96	7.54	179.	705.

beds (table 13) could be recovered, plus an estimated 10 to 15 million tons (9-14 million metric tons) where the overburden is greater than 200 feet (61 m) thick on the Canyon and Cook beds, for a total of 715 to 720 million tons (648-653 million metric tons). Additional resources might be obtained from the sub-Canyon and local beds, but none were calculated because of the relatively high sulfur content of the sub-Canyon and because of the sparse information available on the thickness and quality of the local beds.

The coal beds underlying the Wall (fig. 1) are considered to be either too thin, of poor quality, or too deep to be considered as potentially minable coal deposits in the Prairie Dog Creek study area, so no resources were calculated for them.

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